Engineering Analysis of Fuel Cells and Hybrid Technologies for Support of the Net-Zero Energy Concept

Net-Zero Energy Conference – Colorado Springs

National Fuel Cell Research Center

UCIrvine | University of California

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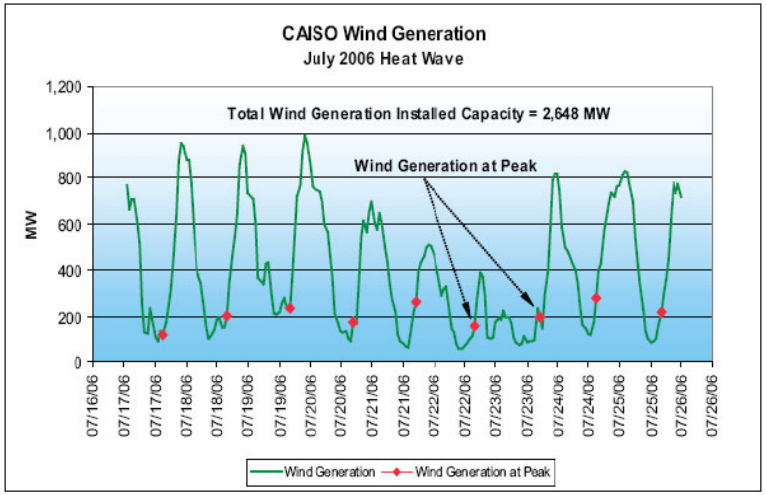
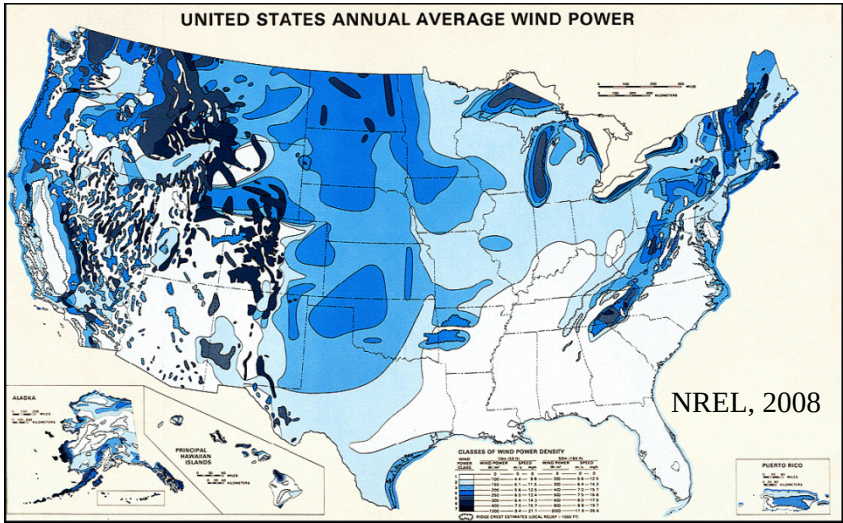
Outline

- Near NZE Thoughts
- Importance of Integration
  - Load Profile Engineering – UC Merced Example
  - Power Park Concept
  - Integration with Transport
- Importance of Dynamics and Control
  - Integrated Residential Fuel Cell Power System
  - Integrated Commercial Building Application

Near NZE Thoughts

- 1st: Do as much Energy Saving, Energy Efficiency as Possible
- 2nd: Use as much Renewable Power as Possible
  - CHALLENGES: Intermittency, Non-Coincidence, Remoteness, Cost, Integration with Demands
- 3rd: "Complement" with Dispatchable Resources: DG, CHP, biomass, hydro
- 4th: Handle Instantaneous Power & PQ w/ Smart Communications and Control





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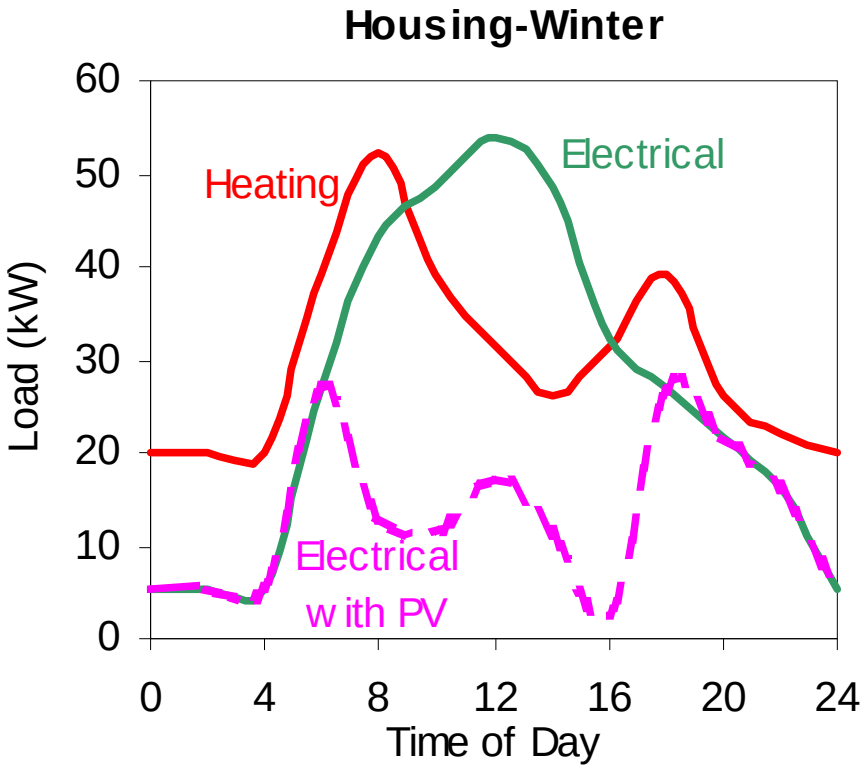
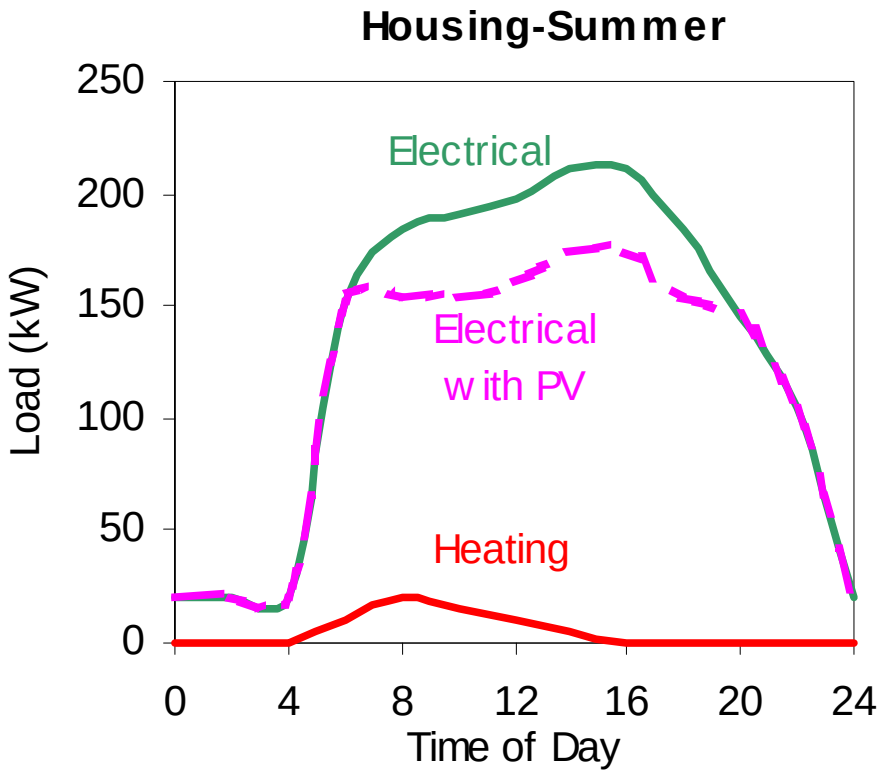
Importance of Integration

Load Profile Engineering – Housing/Residential Building Example

- Very little thermal and low electrical load
- Loads increase during the day to meet comfort requirements with increased activity
- Increased heat load for winter nights
- In summer, electric demand is much greater (cooling)

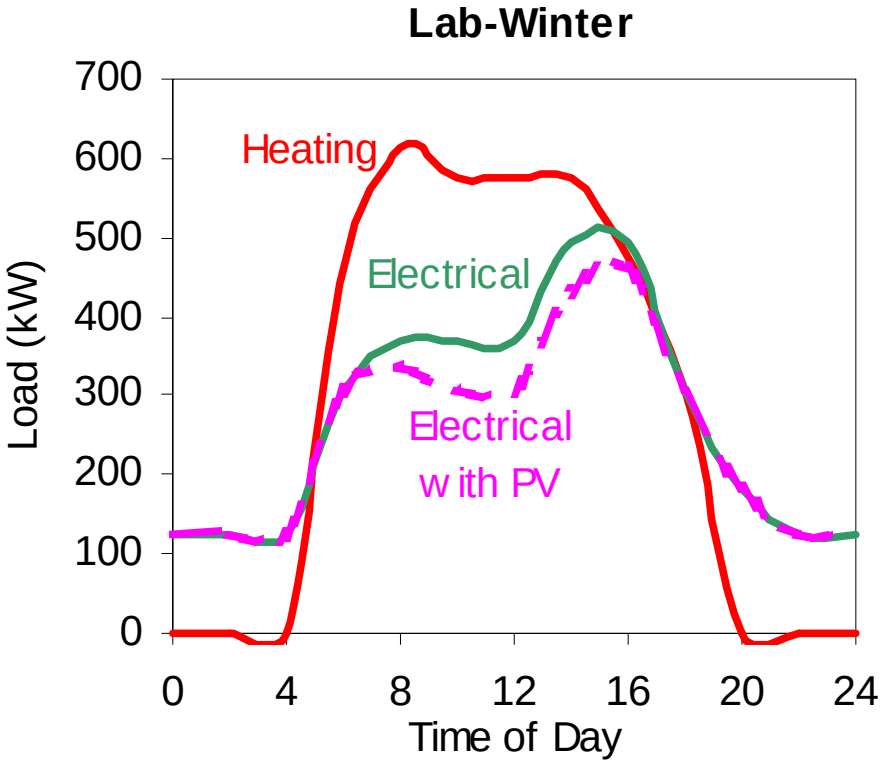


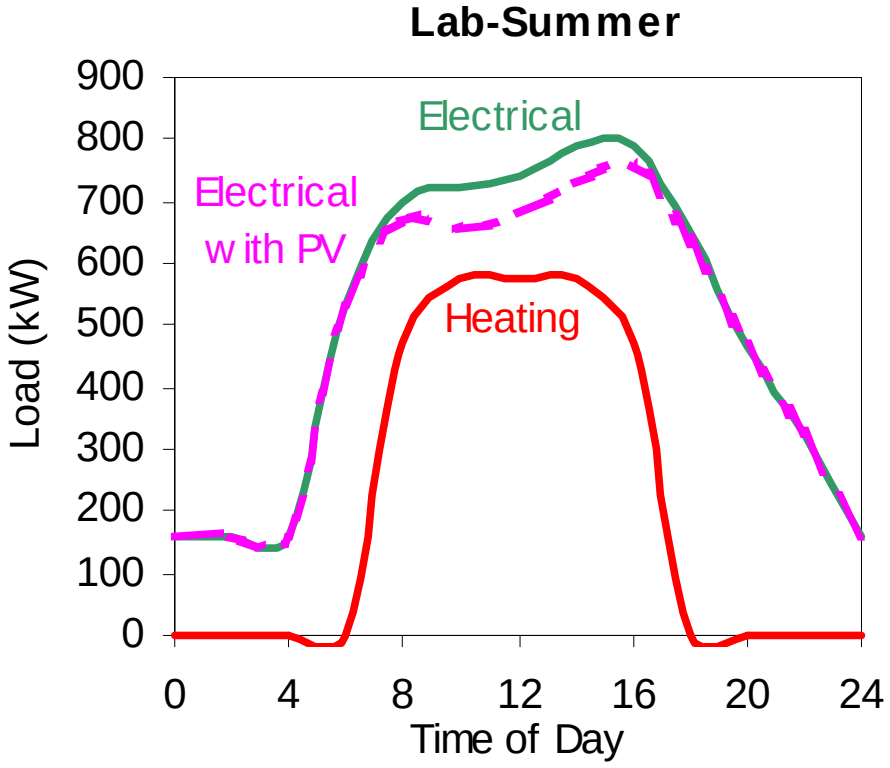


Importance of Integration

Load Profile Engineering – Laboratory/Industrial Building Example

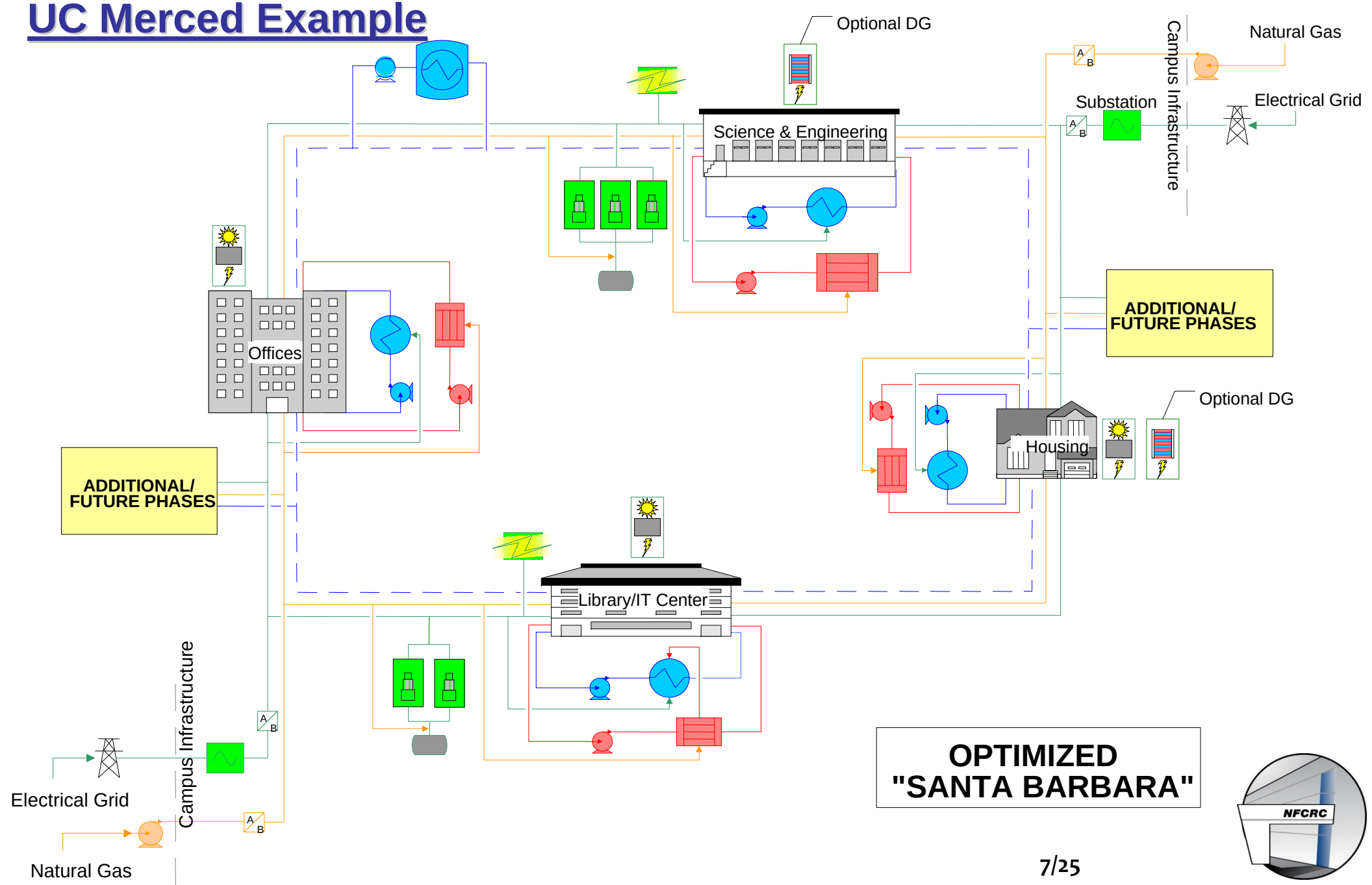
- More energy-intensive requiring large amounts of both electrical and on-demand high temperature hot water
- Heating demands for winter and summer are nearly equivalent due to the 100% air circulation through the building





Importance of Integration

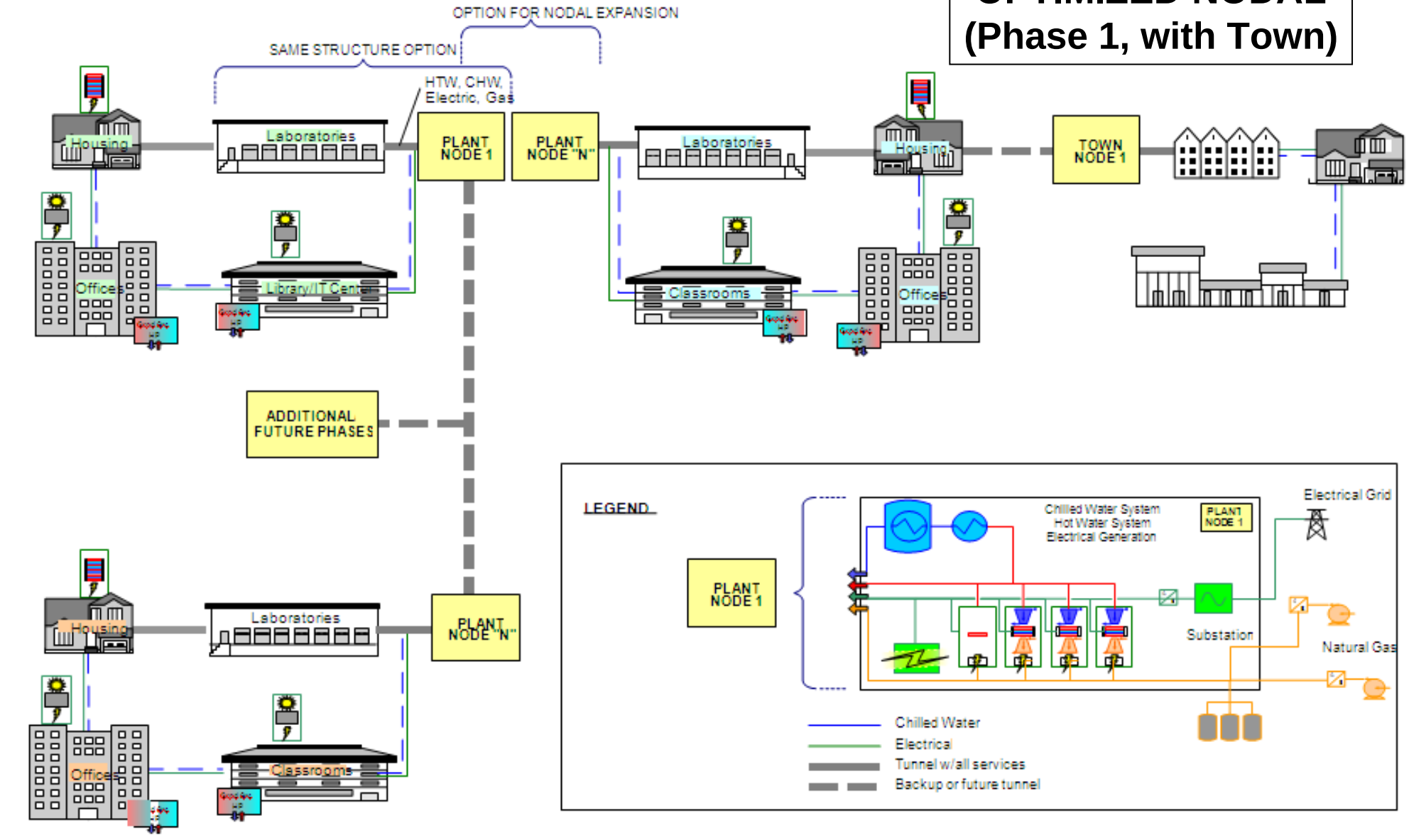
UC Merced Example



Importance of Integration

UC Merced Example

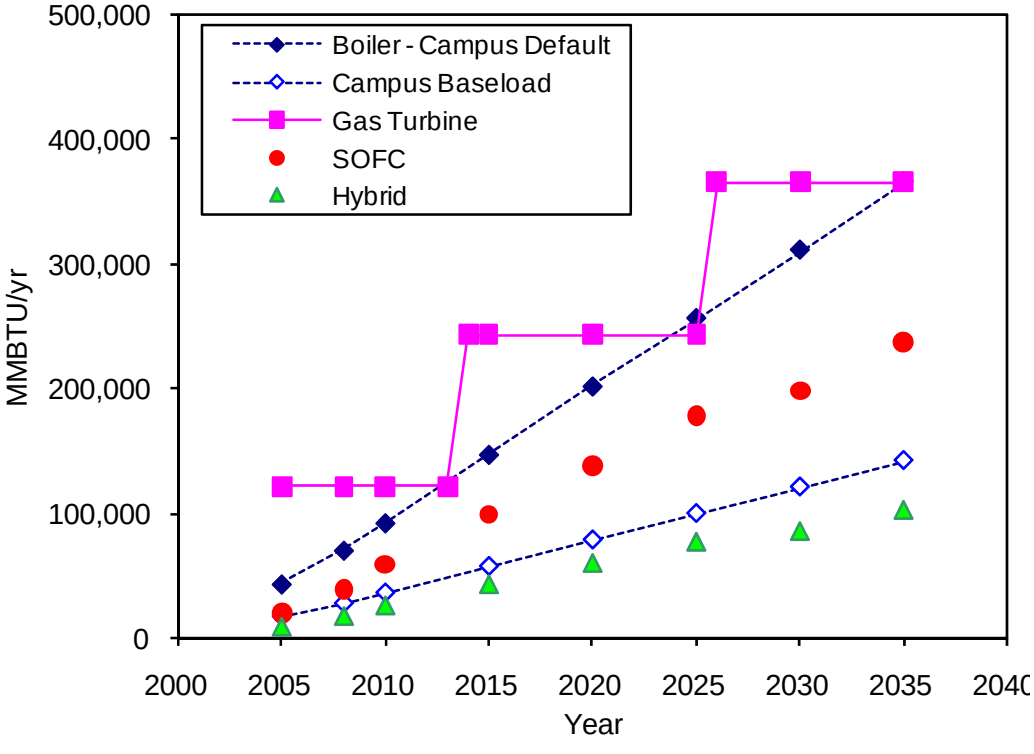
OPTIMIZED NODAL (Phase 1, with Town)

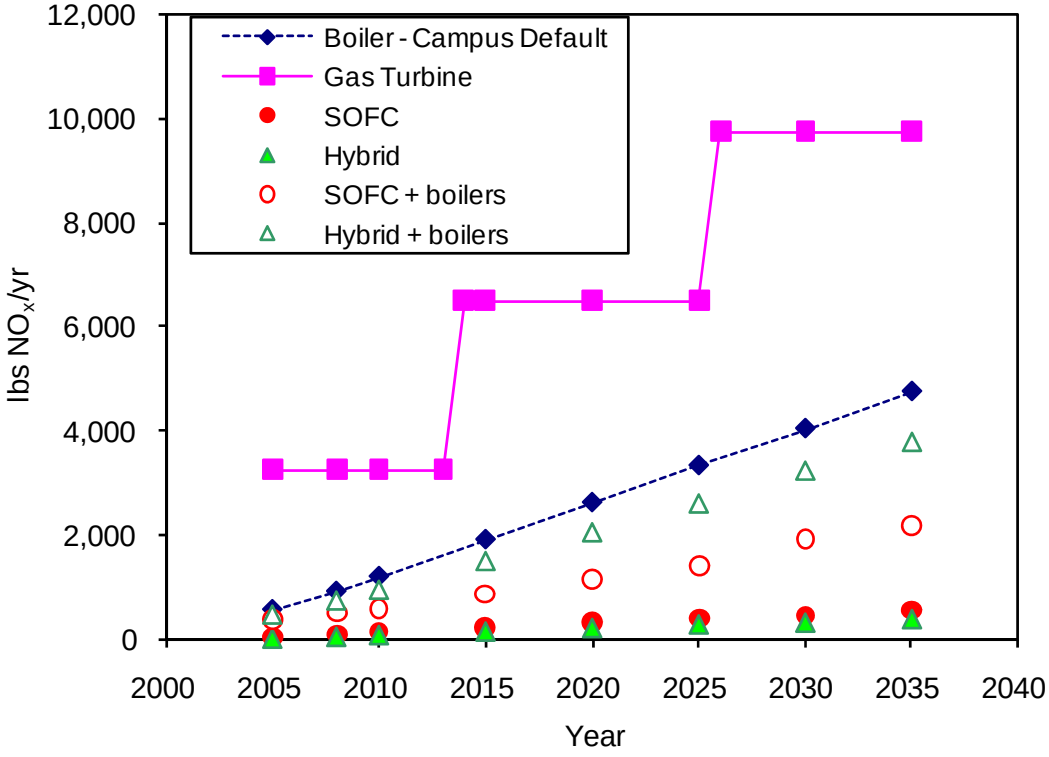


Importance of Integration

UC Merced Example

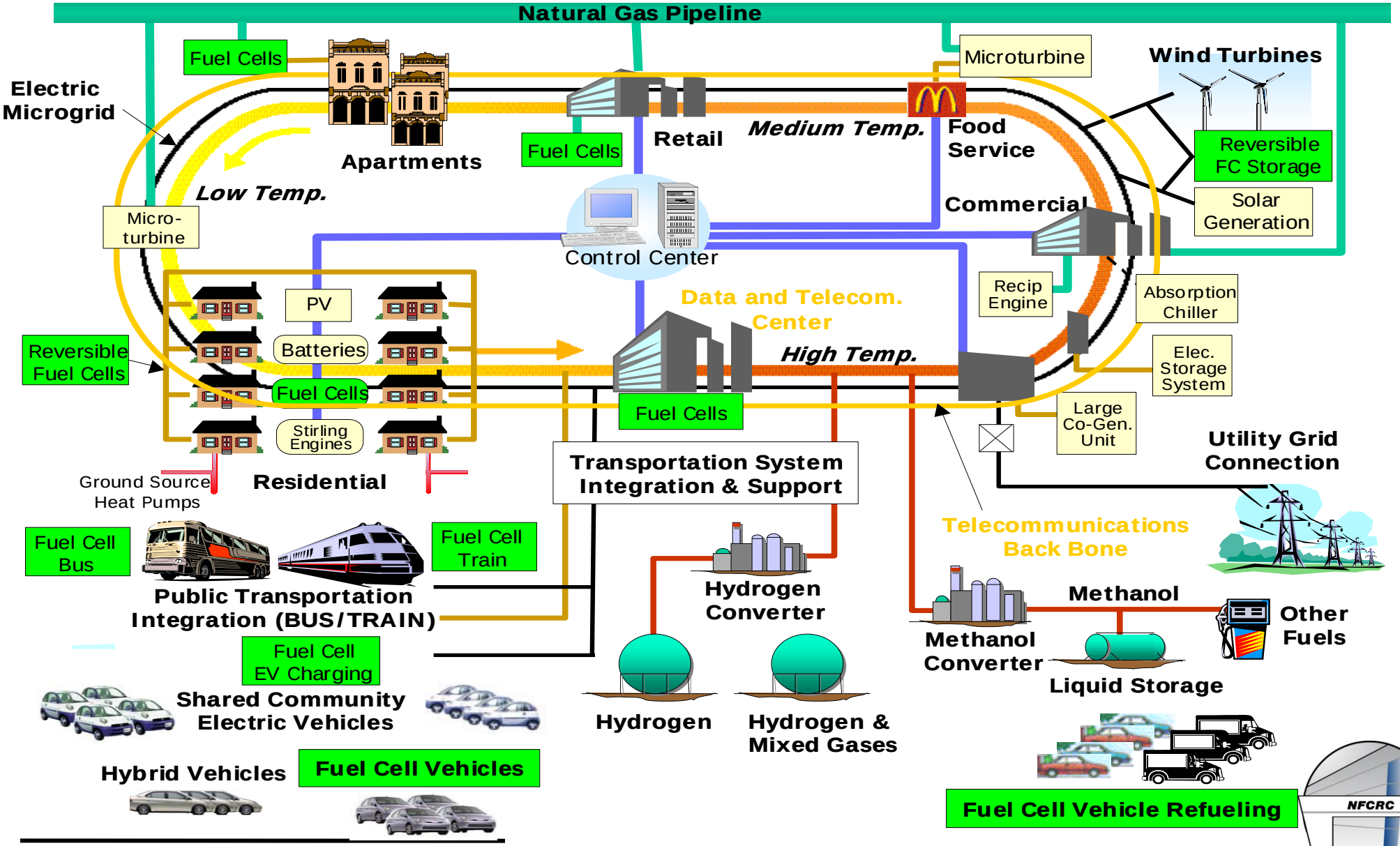
- Emissions and Efficiency estimates
- Phased Integration
- Various phases and technology component options
  - Boilers
  - Gas Turbines
  - Solid Oxide Fuel Cells
  - Hybrid SOFC-GT



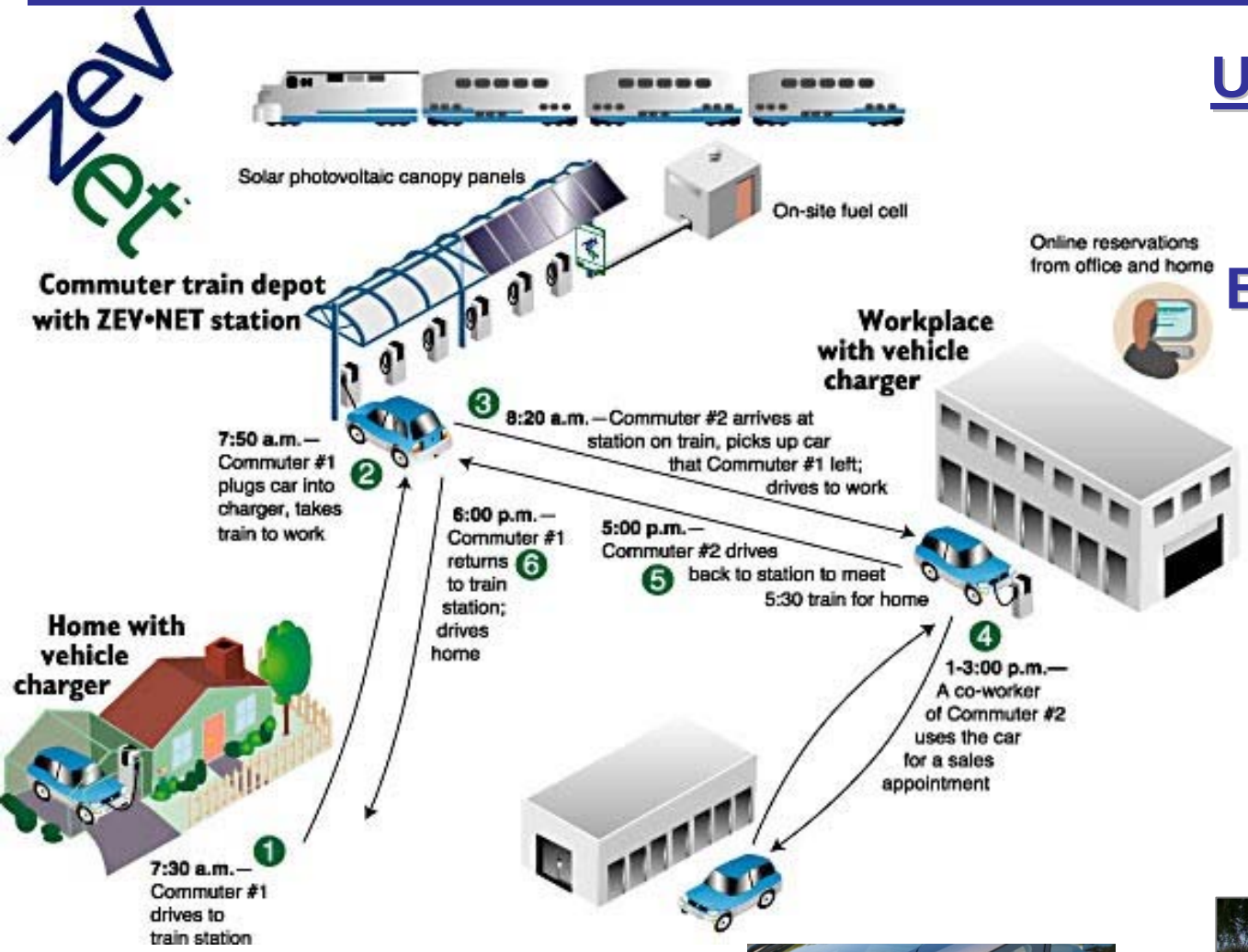


Power Park Concept

Integration is key to energy /emissions savings



Integration with Transport



USE MORE ELECTRICITY

Mass Transit

Battery Electric Vehicles

Plug-in Hybrids

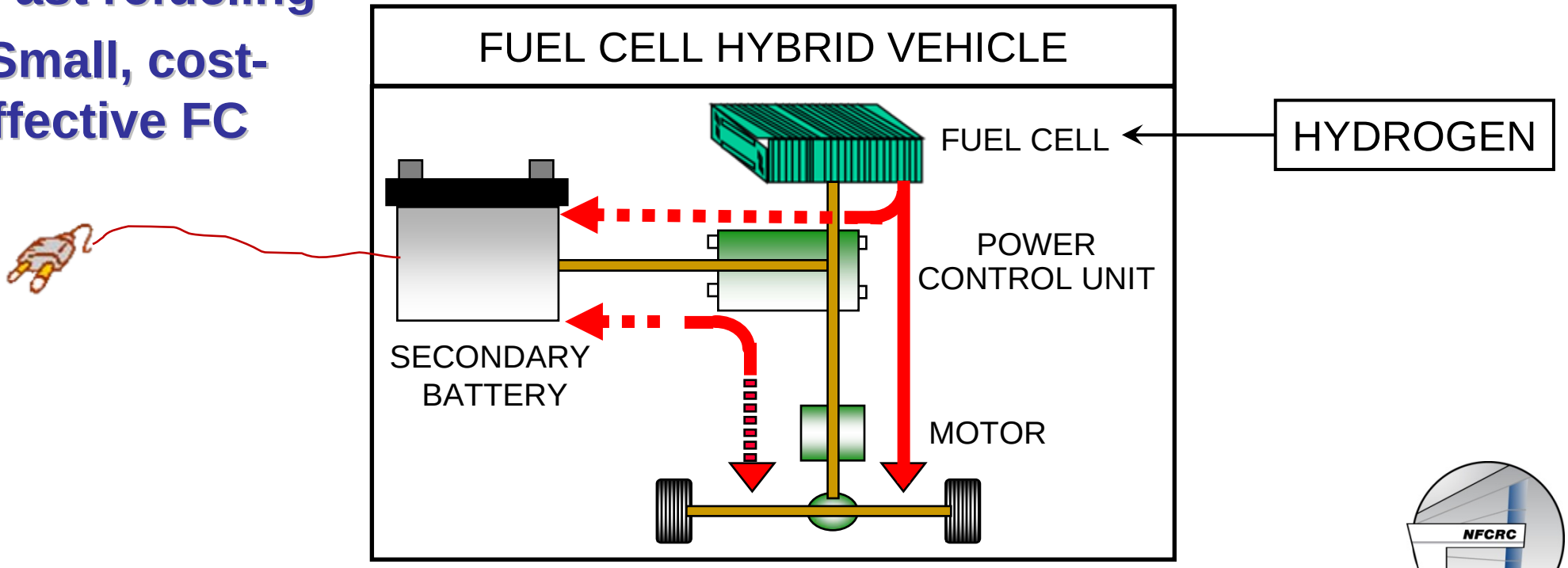
ZEV•NET

TOYOTA

Integration with Transport

Plug-In Hybrid Fuel Cell Vehicle (PHFCV)

- Meet long range driving demands
- Fast refueling
- Small, cost-effective FC



Integration with Transport

Energy Station Concept – locally co-produce H_2

Energy Station

- Electric Power Generation
- Thermal Power Generation
- Hydrogen Generation

"Renewable Energy Station"

•Green Electricity

•Green Thermal Power

•Renewable Hydrogen

NATURAL GAS

LAND-FILL GAS

2009: World's First Renewable High Temperature Fuel Cell Hydrogen Co-Production Demonstration Orange County Sanitation District, Fountain Valley, CA

FuelCell Energy

AIR PRODUCTS

UC Irvine H_2 Fueling Station
350 bar; 700 bar; liquid (future)

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- **Importance of Dynamics and Control**
  - **Integrated Residential Fuel Cell Power System**
  - **Integrated Commercial Building Application**

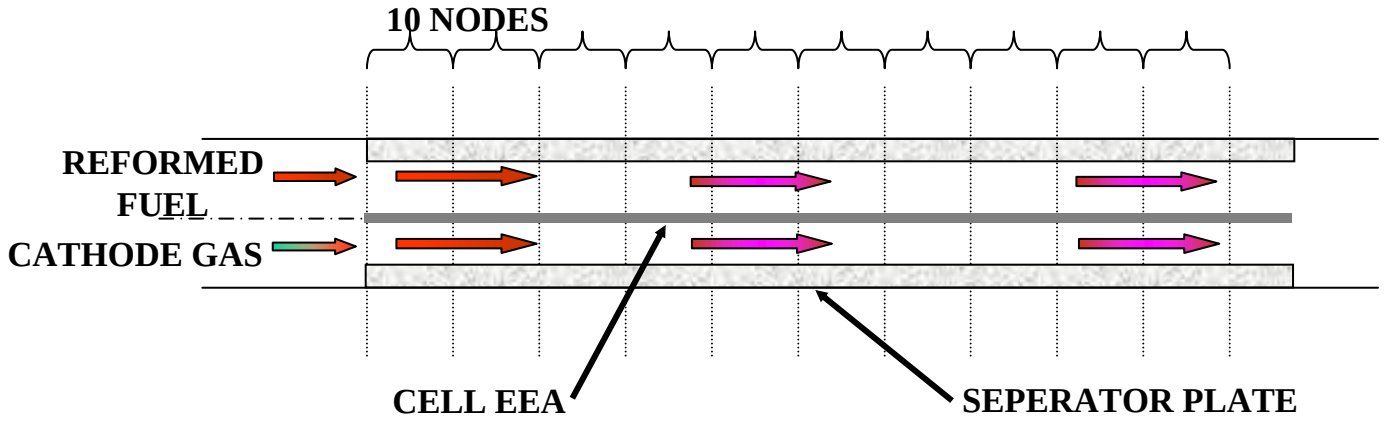
Importance of Dynamics and Control

Dynamic Modeling Tools

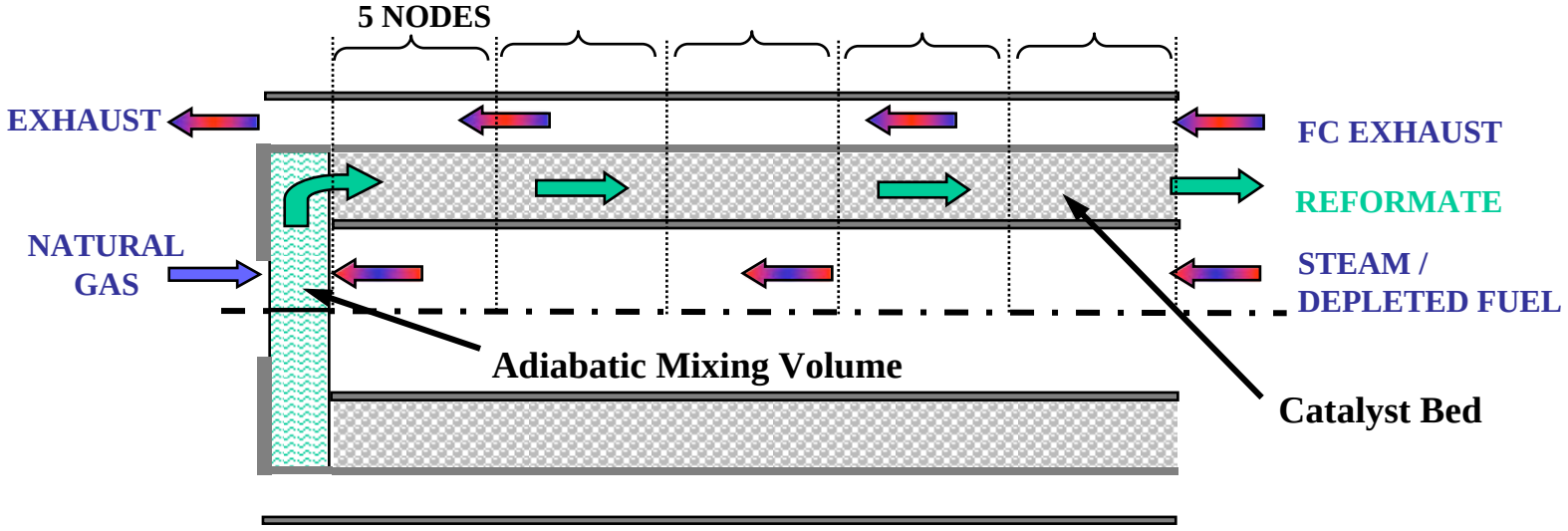
- **MATLAB/Simulink® environment selected**
  - User friendly, widely available/used, ideal for controls development
- **Main assumptions:**
  - quasi-steady state chemistry and electrochemistry (e.g., characterized by Nernst potential and losses)
  - Simplified geometry (but including some geometric resolution)
- **Focus on dynamic solution of the essential FC and other component features such as:**
  - Nernst potential
  - Electrochemical losses
  - Species concentrations and Mass conservation
  - Energy conservation
  - Momentum conservation
  - Heat Transfer
  - Chemical Reaction

Importance of Dynamics and Control

- **Planar SOFC with 10 Discrete Computational Nodes**
  - **Anode Gas, Cathode Gas, Cell EEA, Separator Plates**

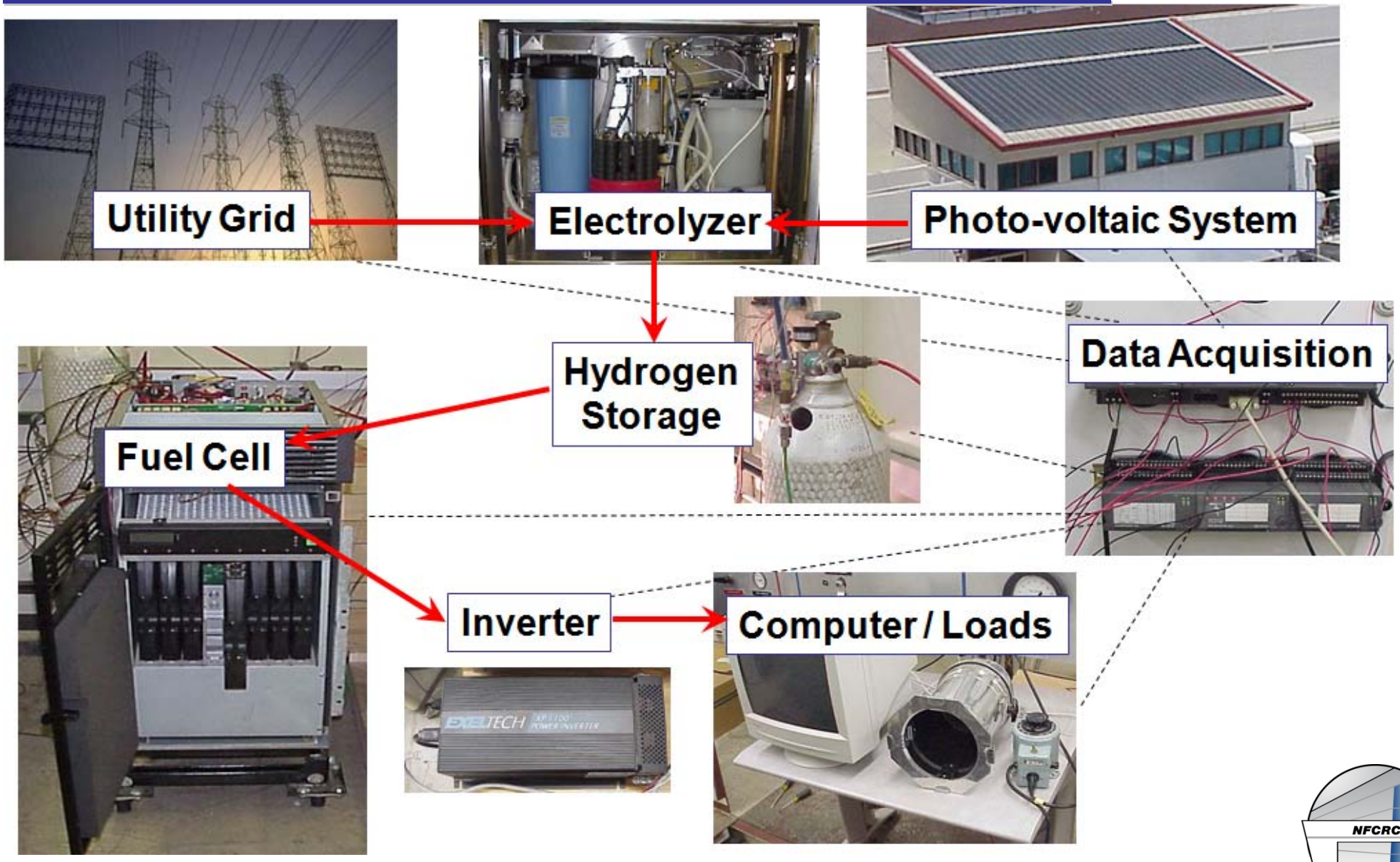


- **Reformer Module with 5 Discrete Computational Nodes**
  - **Anode Off-Gas Recycle, Fuel Mix, Combustor HX, Catalyst Bed**



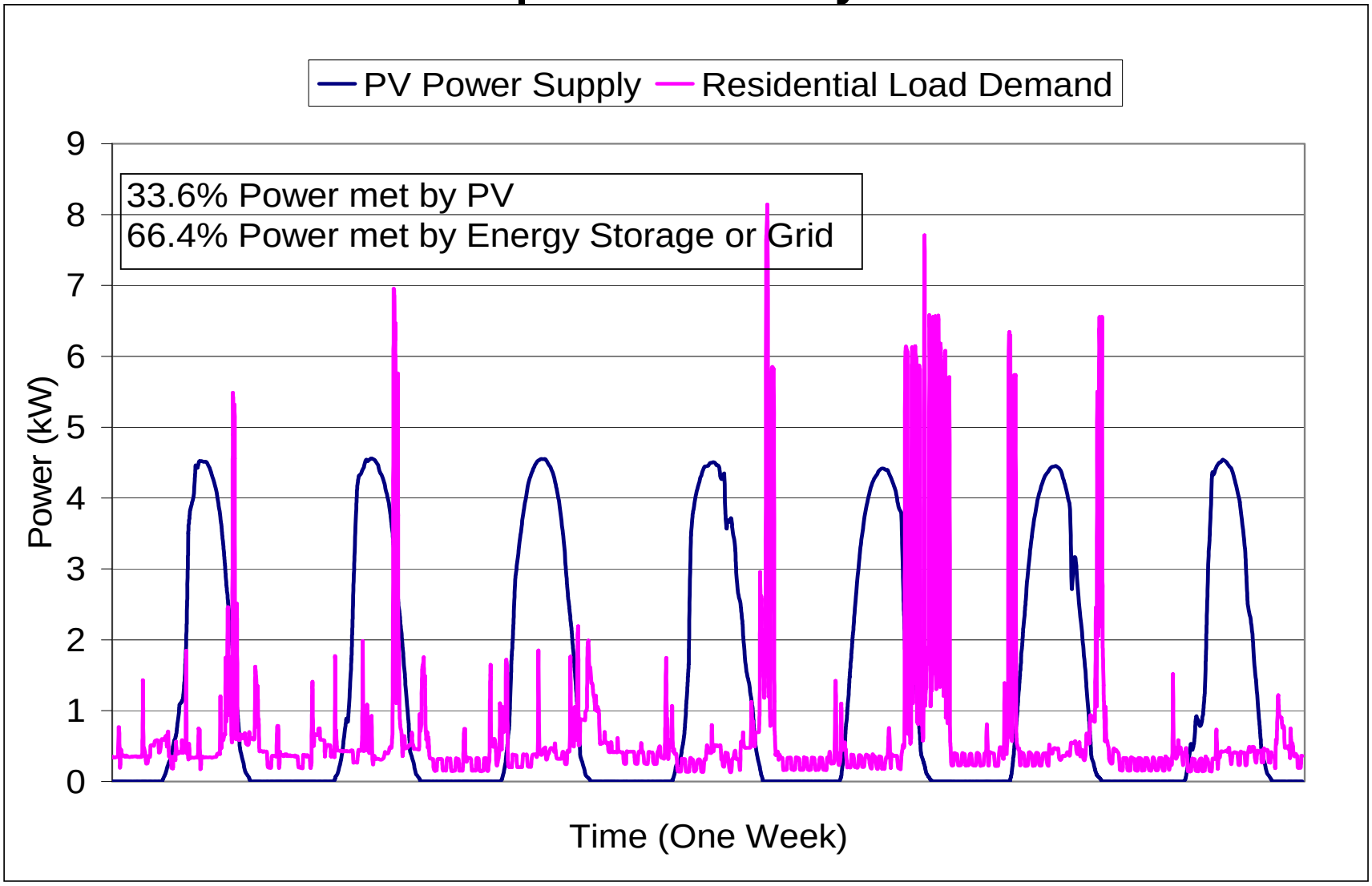
Importance of Dynamics and Control

Integrated Renewable Residential Fuel Cell System



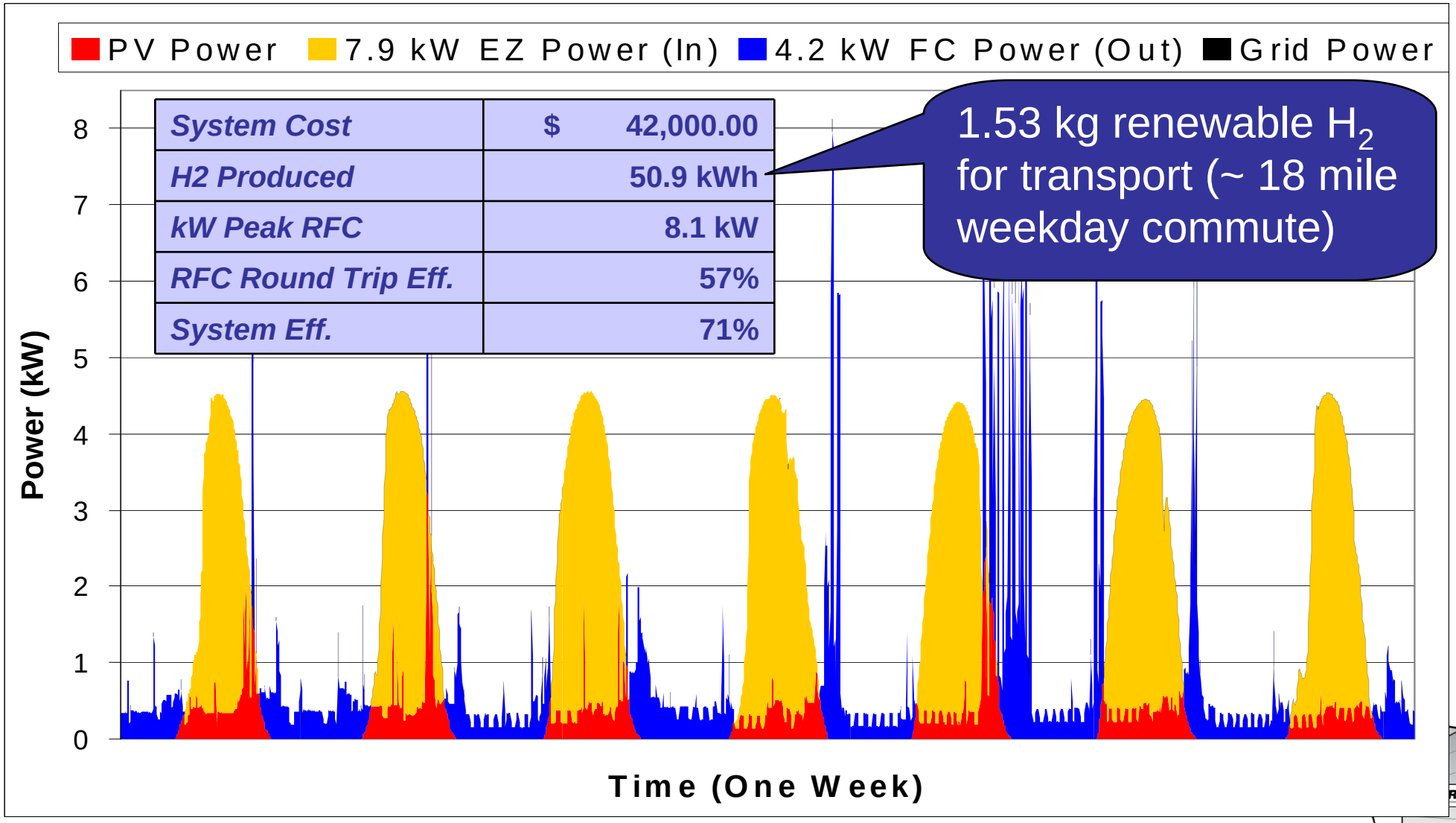
Importance of Dynamics and Control

- **Energy storage is needed to supply the majority of power demand in residential stand-alone photovoltaic systems**



Importance of Dynamics and Control

Integrated Renewable Residential Fuel Cell System – 4.2 kW FC & 7.9 kW EZ Supply & Demand Power Flow

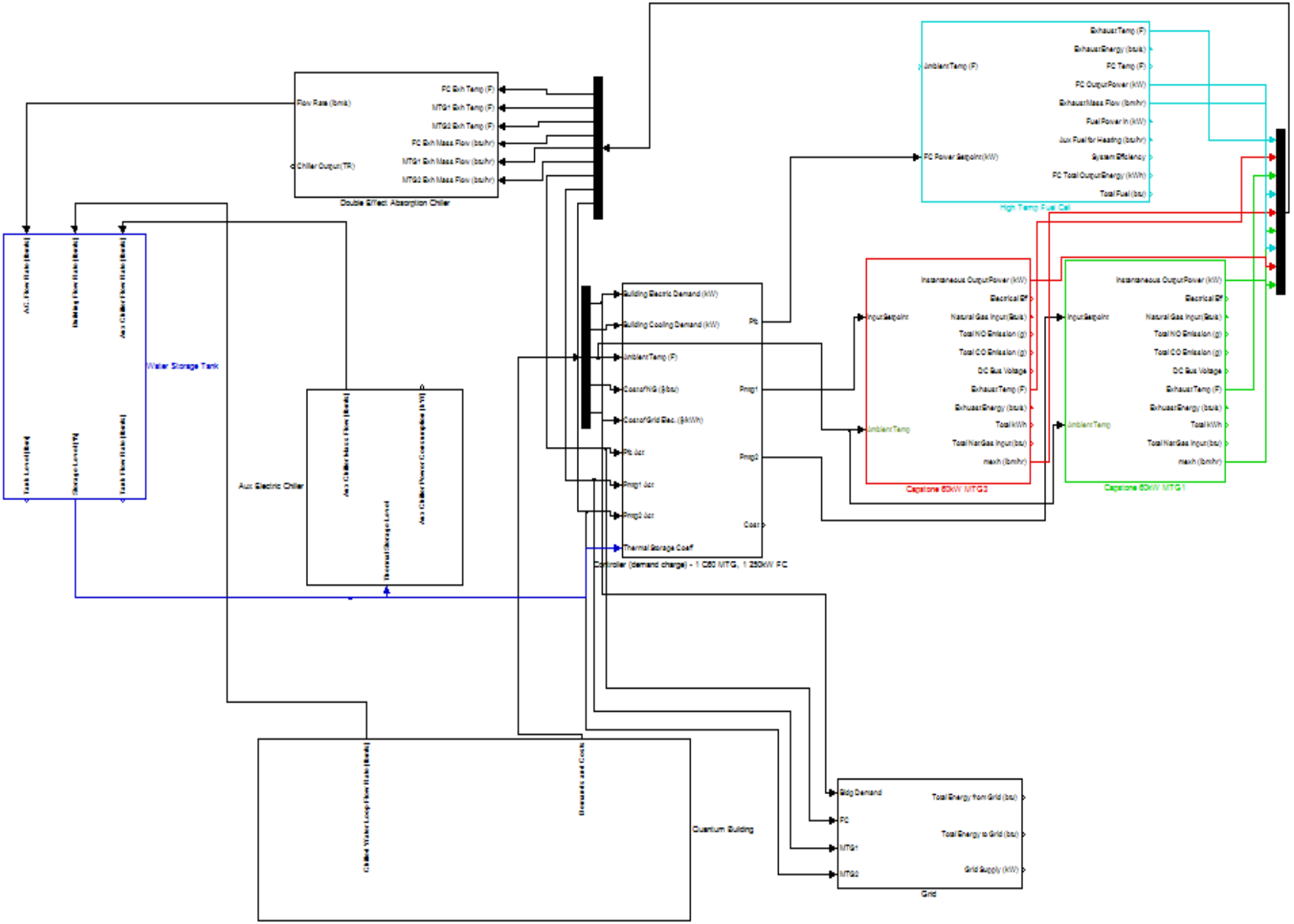


Importance of Dynamics and Control

UC Irvine Load Profile Engineering Research:

- Continuously monitoring four commercial buildings in the University Research Park (URP) for more than 4 years

Importance of Dynamics and Control



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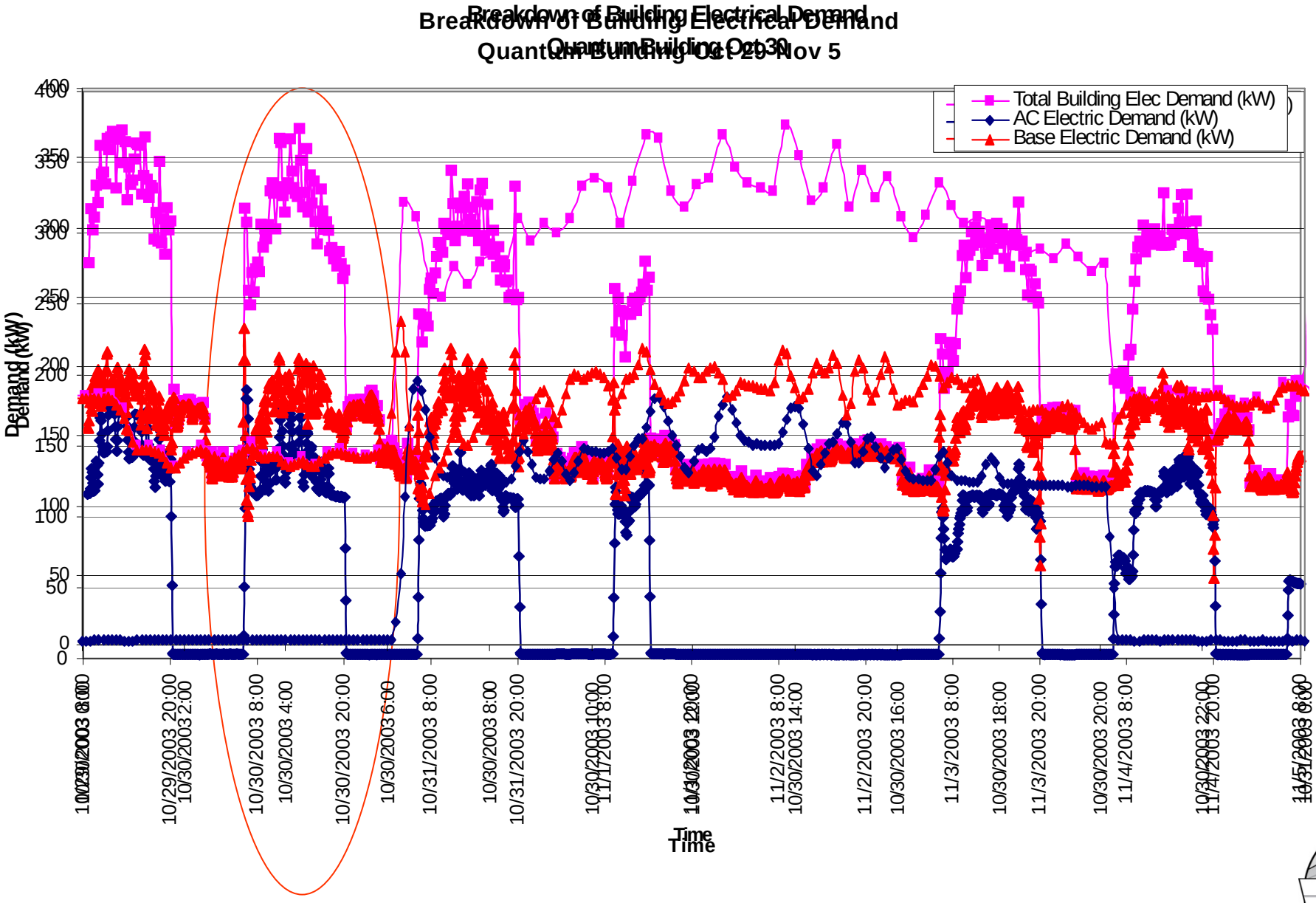


Importance of Dynamics and Control

Basic Cost Equation (without heat recovery):

$$Cost = (P_{bldg} - P_{DG})C_e + \left(\frac{P_{DG}}{\eta_{DG}(P_{DG}, T_{amb})}\right)C_{NG}$$

Cost of Electricity from grid

Cost of Natural Gas

Basic Cost Equation (with heat recovery and thermal storage):

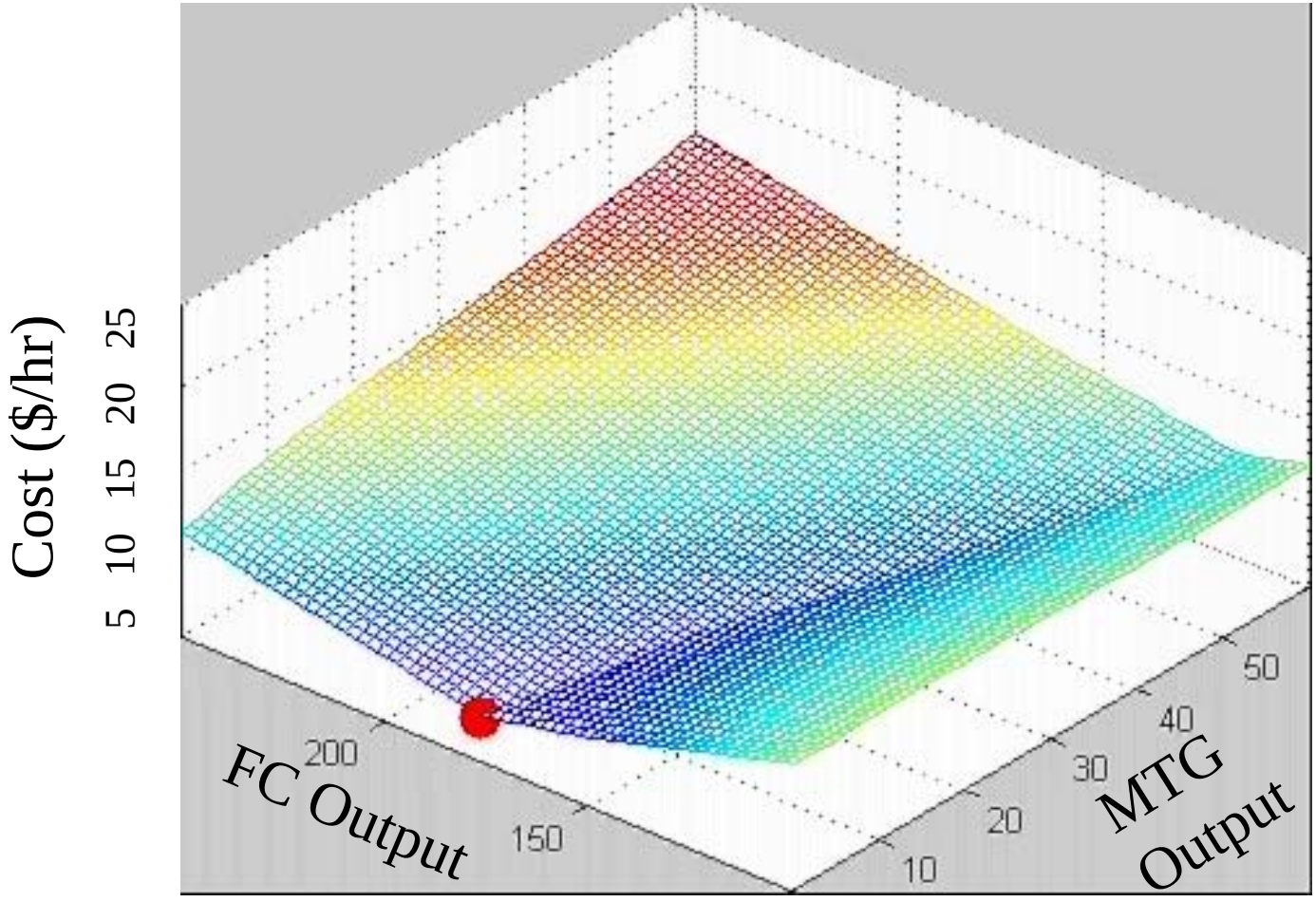
$$Cost = (P_{bldg} - P_{DG})C_e + \left(\frac{P_{DG}}{\eta_{DG}(P_{DG}, T_{amb})}\right)C_{NG} + K_{ws}(Th_{bldg} - Th_{DG}(P_{DG}, T_{amb})COP_{AC})\left(\frac{C_e}{COP_{ec}}\right)$$

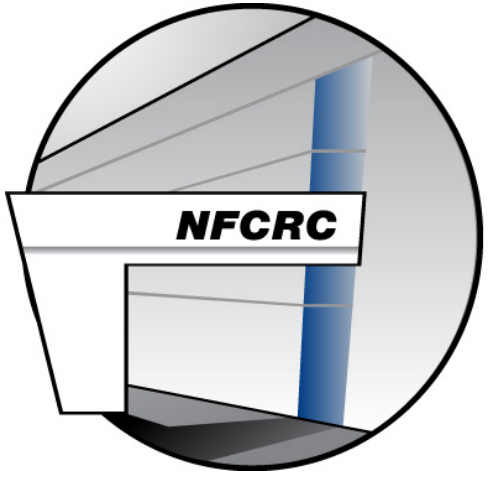
Cost of Thermal Energy

Importance of Dynamics and Control

Minimization of cost function for Quantum Office Bldg., Oct. 30th

1-250 kW FC, 1-60kW MTG, 1.3COP Abs. Chiller





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Thank you for Your Attention!